INTEGRATING FUZZY LOGIC TECHNOLOGY INTO CONTROL SYSTEMS

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Abstract

Among the developments influencing design of control systems are increased levels of functionality needed and new technologies available for implementing those needs. The continued maturing of new hardware and software technologies provides more numerous choices for providing design solutions.

Fuzzy Logic technology is representative of a technology choice which can have a dual identity, appearing in either a hardware or software implementation form. Such an end-to-end capability enables well integrated engineering solutions to be achieved by matching technology to the need. Obviously, a well engineered, successful system is the desired end product. This paper will present a brief overview of fuzzy logic technology characteristics and then lead into a discussion of system design considerations. Examples of alternative operational implementations will be presented.

Introduction

Fuzzy Logic was first developed in 1965 by Lotfi Zadeh, of the University of California at Berkeley. He introduced the theory of fuzzy sets as an extension to traditional set theory, along with the accompanying logic to manipulate the sets.

Since its introduction, fuzzy logic has attracted the attention of many researchers in the mathematical and engineering fields, but only in the last few years have many practical applications of the technology been seen. The pace and quantity of application developments and product releases has been accelerating rapidly, and the breadth of applications is enormous.

Complete development systems for fuzzy logic development have appeared recently, allowing an engineer to quickly design, prototype, and implement a system without worrying about the low levels of the implementation of the fuzzy calculations, and allowing flexible choice of target system processor and other design details after the top level design is done.

In 1989, the first commercial fuzzy logic implementation on a VLSI chip was introduced, giving the fuzzy system architect another choice to help optimize the design tradeoffs.

Overview of Fuzzy Logic

Traditional set theory models the world as very black and white, true or false. An item is either a member of a certain set or not. A fuzzy set allows for degrees of membership in the set. A membership function defines the grade of membership in a fuzzy set for all the possible members, and is typically expressed as a mathematical function or a set of points. This allows human expression and thinking to be more closely modeled. For example, traditional set theory allows us to define the set of people taller than six feet, which would totally exclude a person with a height just a fraction of an inch shorter than the limit. With fuzzy sets, we could define a set of tall people that would include a person just under six feet, but to a lesser degree than a seven foot person.

The common language terms used to describe a fuzzy set, such as "hot," "cold," "high," or "low," are known as linguistic variables. The modifiers to these variables, such as "very" and "about," are known as linguistic hedges, and serve to reshape the membership functions by making them narrower or broader, for instance.

An example of some membership functions for the temperature of a room are shown in Figure 1. Note that the current room temperature is a member of the fuzzy sets "comfortable," and "warm," but with membership grades of approximately 30% and 70% respectively.

Contrast the fuzzy view with the sudden transitions between temperature regions of the more traditional view in Figure 2.

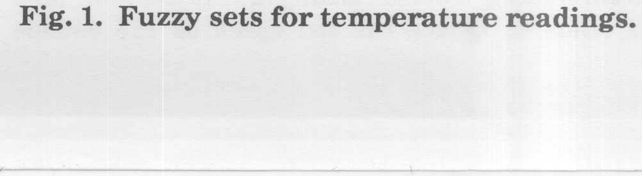

Fig. 1. Fuzzy sets for temperature readings.

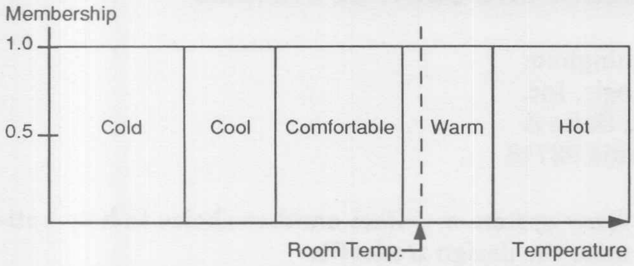

Fig. 2. Crisp sets for temperature readings.

Fuzzy sets become much more useful by defining a "fuzzy logic," a set of logical operations to parallel the Boolean logic that accompanies traditional set theory. Complex expressions can be built by combining fuzzy variables with the fuzzy logic operators. Consider, for example, the expression "person is tall AND person is thin AND person is old." The definition of the fuzzy AND operator determines the resultant value of this expression for a given person, which is again expressed as a degree of truth, rather than a true or false Boolean result.

Fuzzy expressions can be used in a set of IF-THEN rules to define the desired output or result. Since several of the IF sides of the rules may be true to some degree at the same time, the THEN sides of the rules are combined in some relation to the degree of truth of the IF side. This creates a smooth and continuous output change as the inputs change and the relative dominance of the rules change.

Several steps are involved in the process of calculating the final result of a set of fuzzy production rules for a system. Once the value of the IF side is calculated, an inference method is applied to determine the THEN outcome. The various THEN sides are then combined via a fuzzy composition method. The way the whole combination is converted from a fuzzy value to a single 'crisp' value is called the defuzzification method. There are several inference, composition, and defuzzification methods available, the choice of which depends on the application and the desired characteristics of the system.

As an example, Figure 3 illustrates the max-min inference method combined with centroid defuzzification. Two of the rules to control the intake fan speed of a theoretical climate control system are shown. If the room is Warm and the outside air is Cool or Cold, then the intake fan will bring in some of the outside air. In general, the warmer the room is, the higher the fan speed will be (in fact there would likely be a few more rules regarding what to do if the room was Hot), but in order to prevent an uncomfortable blast of winter air from freezing a person sitting next to the vent, Rule 2 tends to reduce the fan speed as the outside temperature passes out of the Cool region and into the Cold region.

In these rules, the value of the statement Room_temp IS Warm is calculated by finding the intersection of the Room_temp and Warm membership functions. Since Room_temp is a crisp (single valued) variable, the intersection with the fuzzy Warm membership function is simply the grade of membership in Warm at that temperature. The fuzzy AND is defined as a minimum operation, so the IF side of each rule is evaluated by taking the minimum truth of the two statements on either side of the AND. (Intuitively, the combined truth can be no greater than the least true statement in the expression). This value is used to clip the membership function of the THEN (output) side.

The outputs of all the active rules are combined by taking the union (maximum) of all the output membership functions, yielding a fuzzy output value. Finally, to make the result useful in control, the output must be defuzzified (a single crisp value selected to represent the fuzzy value as appropriately as possible). Centroid defuzzification takes the center of gravity of the shape of the membership function. In the example, the result is somewhere between Slow and Fast, but closer to Fast, since the truth of the premise of Rule 1 was greater than that of Rule 2.

Fuzzy logic is an extension of traditional logic. In fact, it can be shown that Boolean logic is a special case of fuzzy logic (with restrictions such as limiting the values of the membership functions to 1 or 0, true or false). But fuzzy logic allows much more natural and human expression of the problem at hand, thus making high level design easier and more useful, with many of the low level details, such as making smooth transitions between rules, taken care of automatically by the mechanisms of the logic.

Fuzzy control applications

While the term 'fuzzy logic' might imply that it is inappropriate for precise applications such as controls, it is in fact finding broad application in this area. Fuzzy systems are especially good at handling difficult control problems, such as non-linear systems, time varying or less predictable systems, and ill-defined or difficult to model systems.

The design of control systems using fuzzy rules proves to be quicker for many systems, as the rules are a more human, intuitive way to describe the desired output(s) for a given set of inputs. For instance, many process control applications have

been implemented by converting an expert's description of how he controls the system into fuzzy rules. Most traditional control methods depend on an accurate system model, which may be difficult or impossible to construct in some cases. Fuzzy rules do not rely on mathematical models, but are simple statements of the type 'if this then do that.' This is not to say that models are not useful in the design of fuzzy systems. Models, if available, help the designer determine the minimum required set of inputs, and to mathematically determine many of the points on the desired control surface.

The dynamics of a system require tuning of the membership functions of the inputs and outputs, and choosing inference and defuzzification methods. A fuzzy system can be very quickly and easily be tuned to give the same results as a less sophisticated control algorithm, such as PID control (which only has three factors to tune), but then can be further refined to outperform the simpler algorithms, or even to control systems that are beyond their capability. Fuzzy logic control system tuning is an area which is currently receiving a lot of attention by researchers, including several projects which combine AI and neural network techniques to 'learn' the membership functions.

Some control applications take a more conservative approach, and use fuzzy logic to dynamically tune a more conventional control system. For example, PID controllers can be augmented with a fuzzy controller dynamically retuning the control factors of the PID to adapt to varying conditions.

The flexibility of fuzzy logic has led to a broad range of control applications, including home appliances, consumer electronics, industrial controls, automotive controls, transportation systems, and aerospace. Companies in Japan have developed hundreds of applications to date. The European and American market applications have lagged behind, but are currently heating up.

Non-control applications of fuzzy include pattern recognition, such as Optical Character Recognition

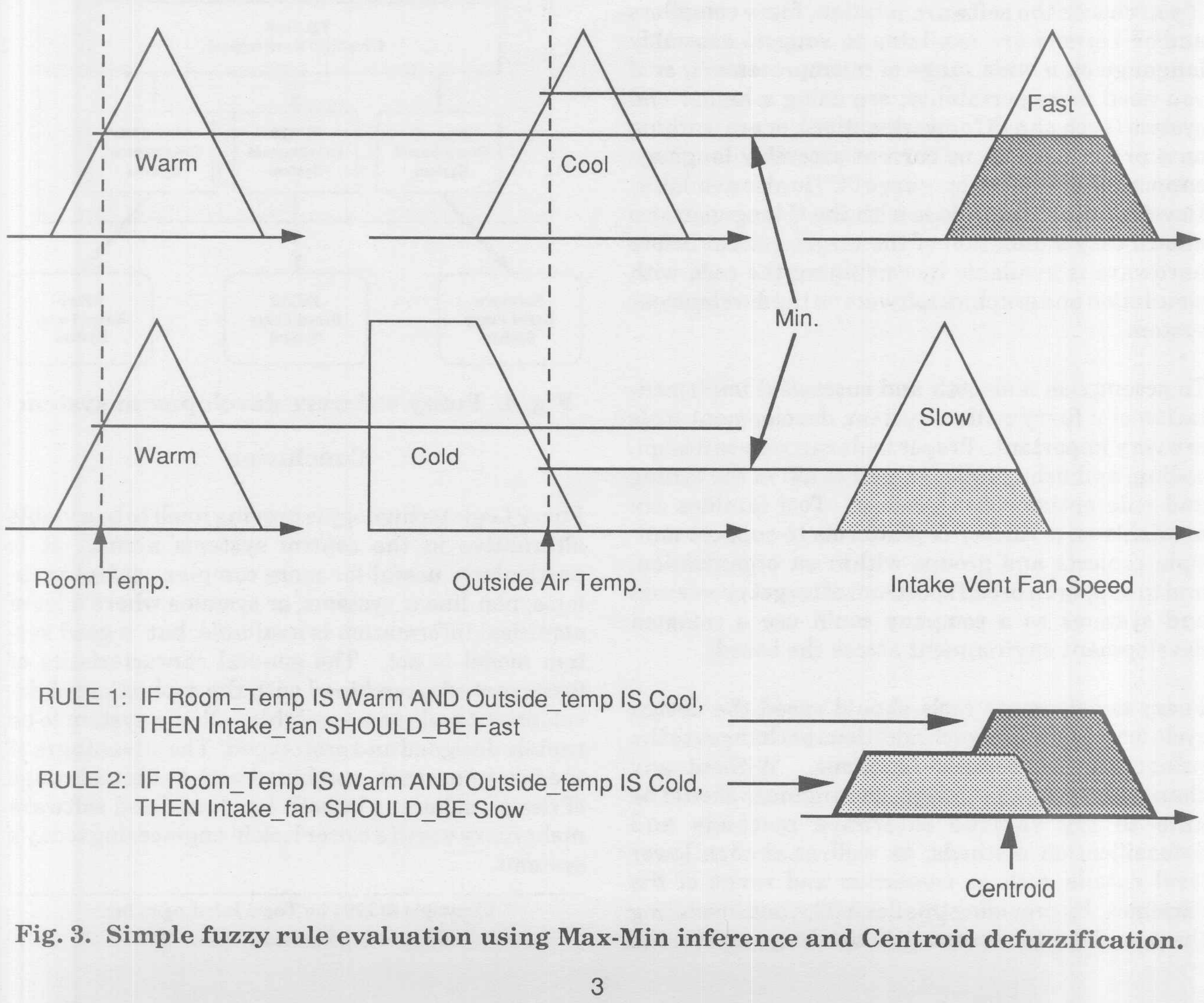

Fig. 3. Simple fuzzy rule evaluation using Max-Min inference and Centroid defuzzification.

(OCR) and machine vision, scheduling, such as building elevator controllers, and financial analysis, such as credit worthiness scoring and stock market trading.

System design considerations

As usual, there are tradeoffs to consider in determining the best way to implement a system based on or using fuzzy logic. The decisions start with hardware versus software, hardware generally being the more expensive route, but offering much faster execution of the fuzzy rules.

On the hardware side, both chip level and board level solutions are available. Industry standard boards and proprietary single board fuzzy computers and accelerators are available and suitable for prototypes or small to medium production runs. For larger volume products, or products with unique packaging or interface requirements, you can incorporate fuzzy logic accelerator chips into your custom designs.

If you choose the software solution, fuzzy compilers and/or kernels are available to support assembly language on a wide range of microprocessors, or if you need more portability, are using a higher end system (such as a PC or workstation), or are working on a processor with no current assembly language support, higher level language ('C') is also available. Developing the fuzzy code with the C language also allows easy simulation of the target system before hardware is available by combining the code with simulation and graphics software on the development system.

To accomplish a smooth and successful implementation of a fuzzy control system, development tools are very important. Proper tools can reduce design, coding, and debug time, as well as aid in the tuning and rule optimization process. Tool families are available on a variety of platforms to support multiple projects and groups within an organization, and to support a broad spectrum of target processors and systems so a company could use a common development environment across the board.

Fuzzy development tools should speed the design cycle loop, allowing quick additions or changes to the rules and membership functions. Without any changes to the basic design, the engineer should be able to try various inference methods and defuzzification methods, as well as change lower level details such as resolution and range of the variables. By providing this flexibility, and insulating the user from the source code to a large extent, the user can concentrate on the design and tuning of the system, rather than the lower levels of the implementation. This encourages experimentation which may lead to a reduction of the rules required to get an acceptable solution, with a corresponding reduction in processing time and code and data size. Better still, the experimentation enabled by such tools may yield a system with fewer sensors and inputs than originally thought to be needed, effecting a reduction in system cost and complexity.

Figure 4 illustrates an integrated family of fuzzy software development tools available from Togai InfraLogic, including support for C and assembly language output, as well as Togai's fuzzy RISC processor, the FC110. The top level includes a common fuzzy CASE graphical environment available on many of the popular development platforms.

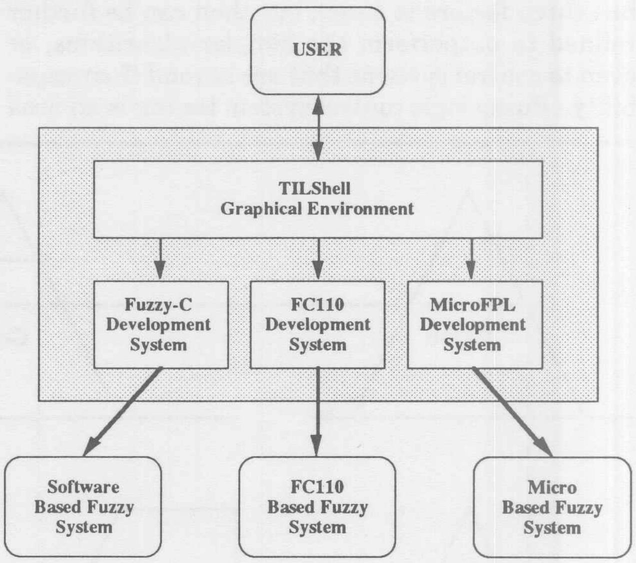

Fig. 4. Fuzzy software development system

Conclusion

Fuzzy Logic technology is proving itself to be a viable alternative in the control systems arena. It is particularly useful for more complex control problems, non-linear systems, or systems where a lot of empirical information is available, but a good system model is not. The general characteristics of fuzzy controls, combined with the sophisticated development tools now available, allow a system to be rapidly designed and prototyped. The advantages of the fuzzy approach, combined with the broad range of design solutions in both hardware and software make fuzzy worth a closer look in engineering today's systems.

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